1989-11

9th International Workshop on Laser Interaction and Related Plasma Phenomena

9th

INTERNATIONAL

WORKSHOP

ON LASER INTERACTION AND RELATED PLASMA PHENOMENA

6–10 November, 1989

Host

Naval Postgraduate School

Monterey, California 93940, USA

ponsors: Fusion Studies Laboratory – University of Illinois
Naval Postgraduate School
University of New South Wales
U.S. Department of Energy
Fusion Power Associates

9th INTERNATIONAL WORKSHOP ON LASER INTERACTION AND RELATED PLASMA PHENOMENA

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Table of Contents

Program

9th International Workshop on Laser Interaction and Related Plasma Phenomena
Naval Postgraduate School, Monterey, California
November 6-10, 1989

SUNDAY, November 5, 1989

7:00 - 9:00 p. m. - Informal Reception and Registration
NPGS Ingersoll Hall

MONDAY, November 6, 1989

8:00 - 8:30 a.m. - Registration, NPGS Ingersoll Hall

8:30 a.m. - Welcome and Announcements - H. Hora/G. Miley/F. Schwirzke

8:45 a.m. - Interaction Physics I (F. Schwirzke, Session Chm.)

B. Luther-Davies, H. Hora, et al. (ANU)	"Periodicity of Backscattered Spectra Explained by Doppler Effect"	(20 min.)
G. Min, L. Cicchitelli, H. Hora, G. Kasotakis, and R. Stening (U. New S. Wales)	"Laser Fusion: Explanation of Stuttering Interaction with its Suppression and Results on Volume Ignition"	(30 min.)
A. Giulietti (IFAM), S. Coe, T. Afshar-rad, M. Desselberger, O. Willi (Imperial College), C. Danson (Rutherford), and D. Giulietti (IFAM)	"Experimental Study of Beam-Plasma Instabilities in Long Scalelength Laser Produced Plasmas"	(20 min.)

Coffee and Discussion

10:20 - Interaction Physics II (S. Nakai, Session Chm.)

A. Giulietti, D. Batani, V. Biancalana, D. Giulietti L. Gizzi, L. Nocera and E. Schifano (IFAM)	"Analysis of 2ω and $3/2\omega$ Spectra from Plasmas Produced by Laser Irradiation of Thin Foil Targets"	(20 min.)
S. Huller, P. Mulser, and H. Schnabl (T. H. Darmstadt)	"Nonstationary Stimulated Brillouin Backscattering in Inhomogeneous Density Profiles"	(25 min.)
K. Mizuno (UC-Davis), W. Seka, R. Bahr (LLE), R. P. Drake, P. E. Young (LLNL), J. S. De Groot (UC-Davis), and K. G. Estabrook (LLNL)	"Ion Acoustic Parametric Decay Instabilities in Laser-Plasma Interactions"	(25 min.)

A. Bergmann and P. Mulser (T. H. Darmstadt) — "Vlasov Simulation of Nonlinear Langmuir Waves Excited by Resonance Absorption" (25 min.)

12:00 - 1:30 p.m. - Lunch

1:30 p.m. - **Advanced Lasers (J. Knauer, Session Chairman)**

C. B. Collins, F. Davanloo, K. N. Taylor, T. W. Sinor, M. J. Byrd, J. J. Carroll, J. J. Coogan, C. Hong, and T. J. Lee (U. TX-Dallas) — "Status and Issues in the Development of a Gamma-Ray Laser in 1989" (35 min.)

M. A. Prelas and F. P. Boody (U. MO-Columbia) — "Nuclear Driven Solid State Lasers for Inertial Confinement Fusion" (25 min.)

H. S. Peng and H. Z. Shen (SW Inst. of Nucl. Phys. & Chem., China) — "Status of Experimental Investigations of ICF and X-Ray Lasers in China" (30 min.)

Coffee and Discussion

3:30 p.m. - **Advanced Lasers and Interactions (P. Mulser, Session Chm.)**

R. A. M. Maddever, B. Luther-Davies, and R. Dragila (ANU, Australia) — "Pulsation of $1\omega_o$, $2\omega_o$ and $3\omega_o/2$ Emission from Laser-Produced Plasmas" (30 min.)

Heidi Fearn (Max-Planck) and M. O. Scully (U. NM) — "Lasing without Inversion" (25 min.)

T. Boehly, J. Wang, B. Yaakobi, R. S. Craxton, and R. Epstein (LLE) — "Observation of Gain in Ne-Like Germanium and Other X-Ray Laser Developments at LLE" (35 min.)

Y. T. Lee, M. Gee, W. M. Howard, and H. A. Scott (LLNL) — "Non-LTE Physics in Modeling of Resonance Lines from Laser-Produced Plasmas" (30 min.)

S. Eliezer and Z. Henis (SOREQ) — "Laser Induced Transitions in in Muon Catalyzed Fusion" (25 min.)

Tuesday, November 7, 1989

8:30 a.m. - Announcements

8:40 a.m. - **Overview presentation, ICF**

G. J. D'Alessio (DOE) — "U. S. Inertial Confinement Fusion Program Experiments: Results and Implications"

9:20 a.m. - **ICF Studies (G. Velarde, Session Chairman)**

D. R. Kania (LLNL) — "Recent Results from the LLNL Inertial Confinement Fusion Program" (30 min.)

R. P. Drake (LLNL) — "A Survey of Raman Spectra from Laser-Produced Plasmas" (30 min.)

K. Nishihara and S. Nakai (ILE) — "High Density Compression of Hollow Shell Target by GEKKO XII and Laser Fusion Research at ILE Osaka University" (30 min.)

Coffee and Discussion

10:45 - **Interaction Physics III (S. Eliezer, Session Chm.)**

G. H. Miley, O. Barnouin, A. Procoli, and H. Chung (U. IL) — "Radiation Damage in Single and Polycrystal CsI" (25 min.)

R. R. Peterson (U. WI-Madison) — "Investigations into X-Ray Damage to the First Wall of the Inertial Confinement Fusion Laboratory Microfusion Facility" (30 min.)

H. Kislev and G. H. Miley (U. IL) — "Saturable Magnetics for Laser and Plasma Interactions" (25 min.)

Lunch

1:30 p. m. - **ICF Drivers (H. Lowdermilk, Session Chm.)**

J. R. Murray (LLNL) — "Glass Laser Drivers for ICF" (35 min.)

T. Kessler (LLE, U. Rochester) — "Glass Laser Technology" (35 min.)

J. J. Ramirez (SNL) — "Light Ion Beam Drivers for Inertial Confinement Fusion" (35 min.)

Coffee

R. O. Bangerter, A. Friedman, D. W. Hewett, D. D. Ho, and A. B. Langdon (LLNL)	"Heavy Ion Accelerators as Drivers for Inertial Confinement Fusion Power Plants"	(35 min.)
D. Cartwright and J. F. Figueira (LANL)	"KrF Laser Driver"	(35 min.)

6:00 p.m. - Social Hour

7:00 p.m. - Banquet

Wednesday, November 8, 1989

Tour LLNL Bus Leaves 7:30 a.m. Returns 5:00 p.m.

7:00 p.m. - **Interaction Physics IV (C. Joshi, Session Chm.)**

F. Caspers and E. Jensen (CERN)	"Particle Acceleration with the Axial Electric Field of a TEM10 Mode Laser Beam"	(25 min.)
C. Joshi, C. Clayton, K. Marsh, D. Hopkins, and A. Sessler (UCLA)	"Demonstration of Frequency Upshifting of Electro-magnetic Radiation by Rapid Plasma Creation"	(30 min.)
S. Eliezer (SOREQ), H. Hora, R. S. Pease (U. New S. Wales), A. Scharmann, and D. Schwabe (U. Giessen)	"Laser-Plasma Double Layers: Generalization to Degenerate Electrons and Nuclei"	(25 min.)

Coffee and discussion

M. Gundersen (USC)	"A Review of the Back-Lighted Thyratron"	(25 min.)
L. Cicchitelli, H. Hora (U. New S. Wales), A. Scharmann, and W. Scheid (Justus Liebig U., FRG)	"Acceleration of Electrons to TeV Energy by Lasers"	(30 min.)
W. Williams and G. Miley (U. IL)	"Nuclear-Induced UV Fluorescence"	(20 min.)
H. Yoneda (ILS, Japan)	"Development of High Power KrF Laser for ICF Laser Driver"	(20 min.)
H. Figueroa and M. A. Gunderson (USC)	"A Proposed Microwave Plasma Mirror"	(20 min.)

Thursday, November 9, 1989

8:30 a.m. - Announcements

8:40 a.m. - **Panel "Views on Future Directions in ICF"**

Moderator: D. Cartwright (LANL)
Panelists: E. Storm (LLNL), J. Knauer (LLE), B. Ripin (NRL), S. Nakai (ILE, Japan), P. Mulser (T. H. Darmstadt)

10:00 a.m. - Coffee and discussion

10:20 a.m. - **Target Physics I (K. Niu, Session Chm.)**

R. L. McCrory, J. M. Soures, C. P. Verdon, F. J. Marshall, S. A. Letzring, S. Skupsky, R. L. Kremens, J. P. Knauer, H. Kim, R. Short, T. Kessler, R. S. Craxton, J. Delettrez, R. L. Keck, and D. K. Bradley (LLE)	"Precision Direct-Drive Experiments on OMEGA"	(40 min.)
G. Velarde, J. M. Aragones, L. Gamez, C. Gonzalez, J. J. Honrubia, J. M. Martinez-Val, E. Minguez, J. M. Perlado, M. Piera, U. Schroder, and P. M. Velarde (Politecnica U.)	"High-Gain Direct-Drive Capsule for ICF"	(30 min.)
P. Mulser (T. H. Darmstadt) and K. Niu (Tokyo Inst. of Tech.)	"Electron Motion in Plasma Irradiated by Strong Laser Light"	(30 min.)

12:00 - 1:30 p.m. - Lunch

1:30 p.m. - **Target Physics II (D. Hewett, Session Chm.)**

K. Niu (Tokyo Inst. of Tech.)	"Adiabatic Compression of Fuel in ICF Target"	(30 min.)
J. J. Honrubia and E. Minguez (Politecnica U.)	"Radiation and Atomic Physics Models for ICF Capsules"	(30 min.)
T. Q. Chang, X. T. He (Inst. of Applied Phys., Beijing, China), and M. Yu (China Nat'l. Nucl. Corp., Beijing)	"Implosion Characteristics of Radiation-Driven for High Gain Laser Fusion"	(30 min.)

3:00 p.m. - Coffee and discussion

3:20 - **Target Physics, III (B. Ripin, Session Chm.)**

X. T. He, T. Q. Chang (Inst. (of Applied Phys., Beijing, China), and M. Yu (China Nat'l. Nucl. Corp., Beijing)	"X-Ray Conversion in High Gain Radiation Drive ICF"	(30 min.)
J. Grun, J. Stamper (NRL), J. Crawford (SW Texas State U.), S. Bodner, K. Kearney, C. Manka, E. McLean, A. Mostovych, S. Obenschain, C. Pawley, B. H. Ripin, J. Dahlburg, M. Emery, and J. Gardner (NRL)	"Measurements of Hydrodynamic Instabilities and Turbulence Produced by Laser-Accelerated Targets"	(30 min.)
D. K. Bradley, T. Boehly, D. Brown, J. Delettrez, W. Seka, and D. Smith (LLE)	"Early-time "Shine-through" in Laser Irradiated Targets"	(25 min.)
W. Seka, D. Brown, T. Boehly, D. Bradley, T. Balasubramanian, and R. Bahr (LLE)	"Self-focusing in Transparent Dielectric Media and Subsequent Surface Break-down and Plasma Production"	(25 min.)
F. Schwirzke (NPG)	"Laser Induced Breakdown and High Voltage Induced Breakdown on Metal Surfaces"	(20 min.)

7:00 p.m. - Post-deadline Papers

(To be announced)

<u>Friday, November 10, 1989</u>

8:30 a.m. - Announcements

8:40 a.m. - **Interaction Physics V (C. Deutsch, Session Chm.)**

B. H. Ripin (NRL)	"Laboratory Space Plasma Physics"	(35 min.)
S. Eliezer, Y. Gazit, and I. Gilath (SOREQ)	"Shockwave Decay and Spallation in Laser-Matter Interaction"	(35 min.)

9:50 a.m. - Coffee and discussion

10:10 a.m. - **Interaction Physics VI (T. Q. Chang, Session Chm.)**

K. Nishihara, H. Yasui, and H. Furukawa (ILE-Japan)	"3-d Particle Simulation of Ultrashort High Intensity Laser Interaction with Solid Density Hydrogen Plasma"	(25 min.)
D. J. Mayhall, J. H. Yee, G. E. Sieger, and R. A. Alvarez (LLNL)	"Two-Dimensional Calculation of Sequential Electron Layer Formation by Crossed Microwave Beams in Air at Low Pressure"	(25 min.)
Y. E. Kim (Purdue U.)	"Fission-Induced Inertial Confinement Fusion for Power Generation and Cold Fusion with Electrolysis"	(25 min.)
H. Szichman, S. Eliezer, and A. Zigler (SOREQ)	"Two-Temperature EOS Effects in Laser Matter Interaction"	(25 min.)

12:00 - Lunch

1:30 p.m. - **Charged Particle Interactions I (C. Choi, Session Chm.)**

C. Deutsch (U. Paris)	"Ion Beam-Dense Plasma Interaction of ICF Interest"	(30 min.)
W. Jiang, C. Zhang, K. Masugata, and K. Yatsui (Nagaoka U.)	"Tight Focusing of Proton Beam and Its Interaction with Targets"	(30 min.)
T. Kaneda and K. Niu (Tokyo Inst. of Tech.)	"Theoretical Analysis of Charge Neutralization of the Intense Light Ion Beam"	(30 min.)

3:00 p.m. - Coffee and Discussion

3:20 p.m. - **Charged Particle Interactions II (W. Jiang, Session Chm.)**

D. W. Hewett, W. L. Kruer, and R. O. Bangerter (LLNL)	"Corona Plasma Instability in Heavy Ion Fusion Targets"	(30 min.)
D. B. Kothe (LANL), C. K. Choi (Purdue U.), and J. U. Brackbill (LANL)	"An Implicit Fluid-Particle Model for Ion Beam-Plasma Interactions"	(30 min.)
K. Kasuya, K. Horioka, Y. Saito, K. Matsuura, N. Tazima, N. Matsuura, S. Kato, and Y. Goino (Tokyo Inst. of Tech.)	"Active Beam-Control and Active Laser-Diagnostic of Intense Pulsed Ion Sources"	(30 min.)

4:50 p.m. - Closing Remarks

8

INTERACTION PHYSICS I

F. Schwirzke, Session Chairman

Periodicity of Backscattered Spectra Explained by Doppler Effect

B. Luther-Davies, H. Hora, et al.
The Australian National University
Laser Physics Center
Research School of Physical Sciences
Canberra ACT 2601, Australia

(Abstract Unavailable)

* * *

Laser Fusion: Explanation of Stuttering Interaction with its Suppression and Results on Volume Ignition

Gu Min, L Cicchitelli, H. Hora, G. Kasotakis, and R.J. Stening

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While laser-fusion matured to an economic solution of fusion reactors on the basis of the present day knowledge of physics of the Athena project, modifications and improvements for the future may provide a wide range for futher reductions. Difficulties due to the very complicate laser-plasma interaction had been bypassed by indirect drive, but these difficulties may be alternativel overcome by explanation of the 10 psec pulsating (stuttering) interaction by a hydrodanamic standing wave and relaxation mechanism (since SRS and SBS are not the reason). This result is presented explaining that the smothing by random phase plates or ISI is not so much due to suppression of hot spots and filamentation but simply by superposition of standing wave fields to suppress Laue-Bragg reflection.
– Further improvement of laser-fusion using the pusherless Yamanaka compression is studied numerically as an adiabatic volume compression and ignition arriving at DT gains up to 1000 and low ignition temperatures due to alpha self-heat and re-absorption of bremsstrahlung.

10

EXPERIMENTAL STUDY OF BEAM–PLASMA INSTABILITIES IN LONG SCALELENGTH LASER PRODUCED PLASMAS

A. Giulietti*, S. Coe, T. Afshar–rad, M. Desselberger, O. Willi, C. Danson+ and D. Giulietti*.

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+ Rutherford Appleton Laboratory, Chilton, Didcot, England.

A plasma of scalelength of the order of 1 mm was produced by focusing four green laser beams of the Rutherford Appleton Laboratory Vulcan laser onto thin foil targets in a line focus configuration. A delayed green laser beam was focused axially into the preformed plasma up to irradiances of $2x10^{15}$ Wcm^{-2}. Delays were chosen that the preformed plasma was underdense and the electron temperatures ranged from 0.3 to 1.0 keV. Several beam plasma instabilities were investigated under those experimental conditions including laser filamentation and whole beam self–focusing, stimulated Brillouin and Raman scattering. The interacting laser beam was smoothed by using a random phase plate and an induced spatial incoherence system. It was found that both these methods give rise to a virtual suppression of self–focusing and to a significant reduction in the levels of the Raman and Brillouin instabilities. In addition, time resolved spectra of SRS and SBS were recorded showing distinct differences when RPP and ISI were used in comparison with the normal coherent laser beam. Experimental data and detailed analysis for both coherent and smooth interaction beams will be presented.

11

INTERACTION PHYSICS II

S. Nakai, Session Chairman

ANALYSIS OF 2ω AND 3/2ω SPECTRA FROM PLASMAS PRODUCED BY LASER IRRADIATION OF THIN FOIL TARGETS

A. Giulietti, D. Batani, V. Biancalana, D. Giulietti, L. Gizzi, L. Nocera and E. Schifano

Istituto di Fisica Atomica e Molecolare, via del Giardino, 7, 56100 Pisa, Italy

Thin plastic foils have been irradiated at 1.064 μm laser wavelength and an intensity up to $5x10^{13}$ Wcm^{-2}. The plasma produced became underdense during the laser pulse and electron temperatures of several hundred eV's were obtained. Second harmonic and three−halves harmonic emission have been studied perpendicularly to the laser beam axis. Time resolved imaging and spectroscopy gave us novel information on the physical mechanisms involved in these processes. The 2ω line was found to be red shifted consistently with the frequency sum between the incident laser light and the Brillouin backscattered radiation. Such an effect was already postulated to explain second harmonic side emission from filaments occurring in an underdense corona. However the occurrence of the sum frequency in a plasma was demonstrated for the first time in our experiment. 3ω/2 spectra showed an intense broadband red−shifted component and a very faint blue component. The spectral features of 3ω/2 light have been analysed in term of vector composition between electron waves generated by two plasmon decay of the laser light and electromagnetic waves. This analysis allowed us to conclude that the TPD plasmons propagate through the $n_c/4$ layer before they couple with the laser photons to generate 3ω/2 harmonic emission.

Nonstationary Stimulated Brillouin Backscattering in Inhomogeneous Density Profiles. S. Hüller, P. Mulser, H. Schnabl, Techn. Hochschule Darmstadt. - - In inhomogeneous density profiles electromagnetic light is partially absorbed and reflected at the critical surface. In those profiles where the reflection is non-negligible the counterpropagation electromagnetic waves cause standing ion density fluctuations which act as a source for backscattering. To study this effect a simplified model based on the usual three wave interaction as well as an extended model using the nonlinear hydrodynamic description of the ion fluid have been investigated. In certain parameter regions at which absorption and reflection at the critical surface are of comparable magnitude no steady state in the evolution of the backscattered light can establish over long time intervals. The spectral composition of the backscattering signal shows a strong competition between the frequency shifted stimulated scattering (SBS) and the unshifted reflection process.

Ion Acoustic Parametric Decay Instabilities in Laser-Plasma Interactions*

K. Mizuno, W. Seka†, R. Bahr†. R. P. Drake††, P. E. Young††, J. S. De Groot, and K. G. Estabrook††

Plasma Research Group, Plasma Physics Research Institute, and Department of Applied Science, UC Davis, LLE†(University of Rochester), and LLNL††

Microwave experiments, and computer simulations have shown that the Ion Acoustic Parametric Decay Instability (IADI) can produce a significant number of hot electrons in a large scale plasma. These hot electrons are a concern in proposed inertial confinement fusion (ICF) studies because they can preheat the target and degrade compression. The ion wave turbulence excited by IADI will also be a source of anomalous resistivity, so that the thermal electrons are strongly heated due to anomalous Joule heating, and the heat flow is reduced. We have extensively studied the IADI in laser-pellet interactions.

The experiments are performed using the GDL and Omega laser facilities at LLE, and the Janus (Phoenix) and NOVA laser facilities at LLNL. The laser is incident normally onto a planar target (CH, Al, Fe, Cu, MO, and AU of 50 μm thickness) with a 1 ns FWHM Gaussian pulse and a maximum energy of 200J. The IADI is studied by monitoring the Stokes sideband of the backscattered (45 and 0 degrees) spectrum near the second harmonic of the laser light. The time resolved spectrum is obtained using an LLNL streak camera combined with 1/2 m monochrometer (resolution of 1Å and 30 psec).

A well defined Stokes mode excited by the IADI is observed. The threshold decreased as the laser spot size increased. The threshold values reached homogeneous-plasma collisional values, and are quite low $(4 \sim 5)\times 10^{12}$ W^1/cm^2, and $(2 \sim 3)\times 10^{13}$ W/cm^2 for 1 and 1/2 μm lasers, respectively. The results are in agreement with LASNEX calculations with a flux limit of f = 0.1. These low threshold values (for both IR and short wavelength green lasers) indicate that IADI is potentially important in a large scale plasma -- even in short wavelength laser-pellet interactions that are applicable to laser fusion experiments. we have also shown that the ionic charge state Z can be measured using the IADI signal without resorting to complicated atomic physics models.

*The research and materials incorporated in this work were partially developed at the National Laser Users Facility at the Laboratory for Laser Energetics, University of Rochester, with financial support from the U.S.D.O.E. under Cooperative Agreement.

The work performed at LLNL is partially supported by the Plasma Physics Research Institute, Department of Applied Science, UC Davis and LLNL.

Vlasov Simulation of Nonlinear Langmuir Waves Excited by Resonance Absorption

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Technische Hochschule Darmstadt, F. R. Germany

High amplitude Langmuir waves can be excited by resonant absorption of laser light in plasmas. In order to study the influence of kinetic effects on the waves the Vlasov equation has to be solved. We use the capacitor model and solve the Vlasov equation by a variant of the method of Cheng and Knorr[1], thus avoiding the numerical noise inherent in particle simulations. These Vlasov simulations provide the full information on the distribution of the electrons in phase space and allow quantitative comparison with fluid dynamic results. The adiabatic law with $\gamma = 3$ is not only confirmed for the early time of evolution but is found to remain valid in the resonance zone until the wave breaks. The waves are strongly damped due to acceleration of electrons to velocities far in excess of the thermal velocity, even for moderate driver strengths. This prevents the waves from breaking outside the resonance region as the amplitude does not reach the breaking limit[2] $n^* \approx n_o \sqrt{v_\phi / \sqrt{3}\, v_T}$. Thus our calculations suggest that wave breaking (loss of quasi-periodicity) may be explained in terms of hydrodynamics, i.e. breaking is necessary for strongly driven waves to fulfill the energy balance[2].

1. C. Cheng and G. Knorr, J. Comp. Phys. **22**, 330 (1976)
2. P. Mulser, H. Schnabl, Las. Part. Beams **1**, 379 (1983);
A. Bergmann, H. Schnabl, Phys. Fluids **31**, 3266 (1988)

ADVANCED LASERS

J. Knauer, Session Chairman

Status and Issues in the Development of a Gamma-Ray Laser in 1989*

by

C. B. Collins, F. Davanloo, K. N. Taylor, T. W. Sinor, M. J. Byrd, J. J. Carroll J. J. Coogan, C. Hong, T. J. Lee

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At the nuclear level the storage of energy can approach tera-Joules (10^{12} J) per liter for thousands of years. However, any plan to use such a resource for a gamma-ray laser poses problems of a broad interdisciplinary nature requiring the fusion of concepts taken from relatively unrelated fields of physics. Our research group has described several means through which this energy might be coupled to the radiation fields with cross sections for stimulated emission that could reach 10^{-17} cm^2. Such a stimulated release could lead to output powers as great as 3×10^{21} Watts/liter. Since 1978 we have pursued an approach for the upconversion of longer wavelength radiation incident upon isomeric nuclear populations that can avoid many of the difficulties encountered with traditional concepts of single photon pumping. Recent experiments have confirmed the general feasibility and have indicated that a gamma-ray laser is feasible if the right combination of energy levels and branching ratios exists in some real material. Of the 1886 distinguishable nuclear materials, the present state-of-the-art has been adequate to identify 29 first-class candidates, but further evaluation cannot proceed without remeasurements of nuclear properties with levels of precision which characterize more familiar optical measurements.

Recently we reported[1] the first observation of a giant resonance for the dumping of the $^{180}Ta^m$ isomer by pumping samples with flash x-rays of relatively modest intensities from a 6 MeV linac in a scheme which is the nuclear analog of the ruby laser. This particular material, the worst of the 29 actual candidates, showed what was at that time the largest integrated cross section ever reported for interband transfer in any nuclear material, 4×10^{-22} cm^2 eV. This was an enormous value for bandwidth funneling to a fluorescent level, corresponding to about 0.5 eV of useful width for the absorption of the pump x-rays. Subsequent studies showed that these giant pumping resonances occurred with a gratifying frequency throughout the table of nuclides. However, concern has lingered that these seemingly favorable structures might lie at high energies of excitation near the threshold for neutron evaporation, and so be associated in some way with the high density of nuclear states expected there. Experiments conducted this year have proven this potentially detrimental situation does not occur. In our most recent experiments, nineteen isomers were successfully pumped with the bremsstrahlung from a 4 MeV linac. The density of nuclear states near 4 MeV should be exponentially reduced from values expected near 6 MeV, and yet most isomers were excited with comparable efficiencies by linacs operated at the two energies. The two poorest of the 29 candidates for a gamma-ray laser, $^{180}Ta^m$ and $^{123}Te^m$, showed the least variation in excitation when the end point of the bremsstrahlung was lowered from 6 to 4 MeV. Still, no other candidates are available, but results for these two would encourage expectations that the great width associated with pumping candidate isomers is concentrated at relatively few discrete transition energies.

1. C. B. Collins, C. D. Eberhard, J. W. Glesener, and J. A. Anderson, Phys. Rev. C 37, 2267 (1988).

*Research Supported by IST/SDIO and Directed by NRL.

ABSTRACT

Mark A. Prelas and Frederick P. Boody, Fusion Research Lab., Nuclear Engineering Program, University of Missouri, Columbia, MO 65211

Nuclear Driven Solid State Lasers for Inertial Confinement Fusion--A new Class of visible excimers have potential uses as pumping sources for solid-state lasers such as Nd:Glass, GGG, GSGG, Alexandrite, and emerald. These fluorescence sources are based on alkali excimers. The alkali metals have very low ionization potential and the excimer lines are in the visible. Hence, the alkali excimers have high intrinsic efficiencies (i.e. $\eta_{int} = h\nu/W$)[1]. Calculations of potential laser efficiencies indicate that nuclear driven alkali excimer flashlamps are competitive with semiconductor laser pump sources.

[1] C.A. Brau, "Rare Gas Halogen Excimers", Excimer Laser, Ed. C.K. Rhodes, 112 (1984).

Post-Deadline Abstract Submitted for
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Status of Experimental Investigations of ICF and X-Ray Lasers in China

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Ten years ago we began to conduct laser fusion program in China. To date two Nd:glass laser facilities,LF-11(1.06µm, 70J,0.3-0.8ns) and LF-12(1.06µm,2x800J,0.2-1.0ns),completed and installed in 1985 and 1986, respectively, have been routinely operated for physical experiments to study basic processes of laser-plasma interactions. A great variety of diagnostics, such as XRD arrays, filter-fluorescer,x-ray pinhole cameras,plasma calorimeters,photodiodes,optical and x-ray streak cameras, OMA and neutron detectors, have been correspondingly developed and activated. Simultaneously, we have established a microfabrication laboratory to develop target materials and target technology.

In 1986, we carried out direct-drive DT-filled glass capsules experiments and yielded 5×10^{4} neutrons using two-beam irradiation. However,our research emphasizes indirect-drive regime. In order to understand hohlraum physics a series of experiments have been conducted,including laser energy absorption efficiency,x-ray conversion efficiency, x-ray spectra,radiation temperature,suprathermal electrons, stimulated Raman scattering,plasma closure effects and so on. Indirect-drive implosions have been planned to be performed for hydrodynamics studies.

In recent years,we have also been involved in x-ray laser research and succeeded in demonstrating soft x-ray pumped 108.9nm Xe Auger laser, 10.57 and 15.47nm Li-like AlXI recombination pumped lasers and five 20-30nm Ne-like GeXXIII collisionally excited lasers with large gain coefficients.

ADVANCED LASERS AND INTERACTIONS

P. Mulser, Session Chairman

PULSATION OF $1\omega_o$, $2\omega_o$ and $3\omega_o/2$ EMISSION FROM LASER-PRODUCED PLASMAS

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We report measurements where we have time resolved the spectra of the $1\omega_o$, $2\omega_o$, and $3\omega_o/2$ emission from plasmas produced by focussing 70-400psec duration Nd laser pulses to intensities above 10^{14}W/cm^2 onto planar targets. We observe repeated bursts of the emission lasting only 10-20psec and typically septated by 30-50psec. During these bursts the emitted frequency has been observed to sweep rapidly across the wavelength band (=50Å wide) indicating the operation of processes that phase modulate the emission. Our theoretical analysis demonstrated that stimulated Brillouin scattering (SBS) saturated by a nonlinear shift of the wave number of the ion-acoustic wave can be responsible for the observed behavior of the plasma emission. Repetitive amplification and quenching of the SBS results in rapid motion of the reflection point thus causing large sweeps of the phase of the emitted light. Both, temporal pulsations and modulation of time-integrated spectra of the back-reflected radiation and its harmonics result in accord with experimental observations.

LASING WITHOUT INVERSION

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ABSTRACT

Our atomic model consists of a three-level system with an upper excited state and two closely spaced lower levels. It is found that this "Λ"-type energy level arrangement allows for gain, without population inversion i.e. can display gain even when only a small fraction of the atoms are in the upper excited state. The Λ quantum beat laser can be realized in several ways,e.g. using microwaves or coherent picosecond excitation to establish coherence between the lower levels or a Raman type interaction. The most obvious application of the Λ quantum beat laser would be to realize laser operation for these wavelengths where population inversion is difficult. The noninversion laser also has the advantage of reduced spontaneous emission noise.

Ninth Workshop of Laser Interaction with Matter
Naval Post Graduate School
Monterey, Ca.

OBSERVATION OF GAIN IN NE-LIKE GERMANIUM AND OTHER X-RAY LASER DEVELOPMENTS AT LLE

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ABSTRACT

We present results and analysis of recent experiments in which collisionally excited soft x-ray lasing has been observed in germanium targets. We present a comparison of various target geometries which include: exploding foils, massive slabs and double-foil targets. We also make a comparison of effect of optical laser wavelength on x-ray laser performance. In these experiments the various target configurations are irradiated with 600-800 ps pulses of 1.06, 0.527 and 0.351 mm light focused to a line of varying length at intensities <10^{13} W/cm^2. We utilize various hydrodynamic, atomic physics and radiation-transport codes to comment on the performance different target geometries.

We present designs for experiments for recombination x-ray laser studies in aluminum (39Å) which will use the GDL laser with a pulse which is compressed to ~10 ps. In preparation for that we have irradiated 1000–2000 Å foils with 100 ps pulses of 351 nm light and have recorded the spatially resolved x-ray spectra. These spectra show the extent to which the hydrogenic and helium-like species expand and recombine.

Finally, we present results of experiments on the photo-resonant pumping of Li-like Fe using the H-like Lyman alpha line of aluminum.

This work was partially supported by the Naval Research Laboratory under Contract N00014-86-C-2281 and by a subcontract from the University of Texas at Dallas.

Non-LTE Physics in Modeling of Resonance Lines from Laser-Produced Plasmas*

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Abstract

Laser irradiated slab targets have been used in many experiments which measure x-ray conversion efficiency or shockwave. Recently, such a target has been proposed as a source of intense radiation for use in backlighting and resonantly photopumped x-ray laser experiments. In this paper, we investigate resonance radiation emitted from slab targets. The physics involved in the modeling consists of hydrodynamics, equation of state, population kinetics, radiative power loss, and line transfer. Both the hydrodynamics and equation of state have been discussed previously. Here, we are mainly concerned with the non-LTE physics such as population kinetics, radiative power loss and line transfer.

In addition, we are interested in resonance line radiation from low-Z targets such as aluminum or chlorine. In these targets, the contribution of radiative power to the total energy is small and usually less than 10%. Therefore, we can divide the calculation into two parts. The first part deals with the hydrodynamics of the slab under irradiation of a laser beam. The second part computes the transfer of optically thick lines in the slab using the temperature and density profiles obtained from the hydrodynamics calculation.

In the hydrodynamics calculations, the heating and expanding of the target is modeled using LASNEX with either the average ion or DCA hydrogenic models. In both of these models, the energy levels depend only on the principal quantum number. All the rate coefficients are estimated from simple analytic formulas. We have verified that the temperature and density calculated with these models agree well with that calculated using more detailed atomic models.

The transfer of optically thick lines in the slab is calculated using escape probability and numerical methods. We have found that the steep gradients of the temperature, density, and velocity in the slab play a very important roll in the line transfer processes. We have also developed simple model to understand the shapes of the emission profiles. To investigate the optimal resonance line intensity that can be generated using slab targets, we have considered different slab thickness, laser intensity, wavelength, and pulse width. Details of these calculations will be presented.

In addition, we will discuss the implication of these results on plasma diagnostics using resonance lines and on resonant photopumped x-ray laser experiments.

*This work was performed under the auspices of the Department of Energy, Contract W-7405-ENG-48.

LASER INDUCED TRANSITIONS IN MUON CATALYZED FUSION

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Nuclear fusion reactions of deuterium-tritium can be catalyzed by muons. When an energetic negative muon (μ) enters a mixture of hydrogen isotopes at a density of the order of the liquid density (4.25×10^{22} atoms/cm^3) the following chain of reactions occurs : a) slowing down and atomic capture of μ, b) muon transfer to higher isotopes, c) μ-molecular formation d) nuclear fusion of the hydrogen isotopes which are kept together by μ. The muon is either released or captured by the nuclear fusion products (sticking). In analyzing the relevance of muon catalyzed fusion (mcf) for energy production, the problem is to maximize the number X_μ of fusion processes catalyzed by a single μ. X_μ is determined by the lifetime of μ and the frequency of the fusion events described above.

In order to achieve a meaningful energy gain in mcf the number X_μ of fusions per muon must exceed 1000, while the present experimental value is about 150. There are three crucial bottlenecks for mcf energy production: (1) the muon transfer process ($d\mu+t\rightarrow t\mu+d$), (2) the mu-molecular formation of $dt\mu$, and (3) the muon sticking. In this work it is suggested that powerful electromagnetic fields can effect the rates of these three processes and enhance the value of X_μ.

The fusion cycle is inhibited by the slow transfer of muons between the ground states of deuterium and tritium. The fraction of muons reaching the deuterium ground state q_{1s} can be decreased (and thus increasing the number of muons transfered from $d\mu$ to the tritium ground state) by changing the route of the muon deexitation cascade under laser irradiation. The muon cascade is determined by a competition between radiative transitions, external Auger transitions, quenching of the muon levels and transfer processes. The muon transfer cross section from the 2s level of deuterium is larger by a factor of about 5 than the transfer cross section from the 2p level. Therefore the following two step process is proposed in order to enhance the rate of the muon transfer (1): (a) a laser induced transition between the levels 2p and 2s of the deuterium (b) muon transfer by collisions to the tritium 2s level. The ground state population of the deuterium q_{1s} under laser irradiation was calculated by solving numerically the rate equations that describe the muon cascade. The results show that a 0.2 eV laser (the Lamb shift in deuterium) with an intensity of about 10^7 W/cm^2 can decrease the value of q_{1s} by a factor of three. Moreover, q_{1s} can be reduced to zero by pulsed X-ray radiation of an intensity of the order of 10^{13} W/cm^2 (for a broadening $\Delta\nu/\nu \approx 10^{-3}$) by the two step process: (a) radiation induced transition from the 1s to 2p level of deuterium (b) muon transfer to the 2p level of tritium.

The rate of formation of the muonic molecule can also be enhanced by strong electromagnetic fields. We consider a three level system of the $dt\mu$ molecule a) a state in the continuum of $t\mu+d$ (b) the bound state of the molecule $dt\mu$ $(J,V)=(1,1)$ and (c) the bound state $(J,V)=(0,1)$. Under the influence of an external field a Stokes transition from the level (a) to level (b) takes place while the transition from (b) to (c) is occuring through an Auger process. The spontaneus decay of (a) and (b) are included phenomenologically. The probability amplitudes of the levels (a) and (b) are estimated assuming a dipole transition. It is shown that for a resonant laser frequency and intensities of 6.10^{9} W/cm^2 the Stokes efficiency (defined as the ratio between Stokes induced transitions and spontaneus decay) is about 50 .

The most serious limitation at present to the efficiency of the fusion chain is the possibility that the muon could stick to the particle produced in the nuclear reaction. The use of pulsed X ray radiation to induce the transition from the level 1s to the level 2p of Helium followed by the muon transfer to the level 1s of tritium is proposed. By solving the rate equations for these three levels (He(1s), He(2p) and t(1s) it is shown that X-ray radiation of about 10^{13} Watt/cm^2 (with broadening $\Delta\nu/\nu \approx 10^{-3}$) can detach the muon from the 1s level of the He and transfer it of to tritium, thus increasing significantly the value of X_μ.

OVERVIEW PRESENTATION, ICF

U.S. INERTIAL CONFINEMENT FUSION PROGRAM EXPERIMENTS: RESULTS & IMPLICATIONS

G. J. D'Alessio, Inertial Fusion Division, Defense Programs, U.S. Dept. of Energy, Wash., D.C. 20545--During 1987 and 1988 several landmark experiments were performed by a number of participants in the U.S. Inertial Confinement Fusion (ICF). As a result, for the first time in the history of the program, there is a consensus that the basic concept of indirect-drive ICF has been experimently validated. ICF experimental activities include the classified Halite/Centurion program at the Nevada Test Site. In addition, indirect-drive implosion experiments are performed on the Nova laser system at the Lawrence Livermore National Laboratory. High convergence ratio implosions have been consistently obtained. At the University of Rochester Laboratory for Laser Energetics, direct drive cryogenic target implosions on the Omega laser resulted in relatively high density D-T fuel compressions. Neutron yields and other key parameters measured in these experiments show good correlation with results predicted by modeling, indicating that we have begun to understand the underlying physical phenomena in a reasonably comprehensive manner. To assist the program in evaluating this new state of knowledge DOE convened a group of independent reviewers who assessed these results in late 1988. They identified additional areas which require investigation before a decision can be made to construct the next large ICF facility. However, they did conclude that such physics data could be acquired within the 5-year timeframe with the appropriate upgrade of present facilities. They also found that the ICF Program's present efforts to plan for a high-gain Laboratory Microfusion Facility (LMF) during the late 1990's are highly appropriate.

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ICF STUDIES

G. Velarde, Session Chairman

RECENT RESULTS FROM THE LLNL INERTIAL CONFINEMENT FUSION PROGRAM *

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Substantial progress has been made during the past several years within the LLNL/Nova target physics program in demonstrating many of the physics requirements for high gain inertial confinement fusion (ICF). A drive uniformity of a few percent has been achieved, hydrodynamic stability has been demonstrated, and low preheat with a shaped drive pulse has lead to a low implosion adiabat. Higher fuel densities have been observed using shaped laser pulses compared to the results achieved with square pulses. In all of these experiments, the target performance is well modeled by 1-D simulations.

Many sophisticated measurements are performed to understand the performance of the targets. These measurements include bang time, burnwidth, neutron yield, shell and fuel ρR, time resolved x-ray imaging, and time resolved x-ray spectroscopy. The measurement techniques and data will be compared to computer simulations of the experiments. The implication of these results for high gain ICF will be discussed.

* This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

INVITED PAPER

9th International Workshop on
Laser Interaction and Related Plasma Phenomena

A Survey of Raman Spectra From Laser-Produced Plasmas

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ABSTRACT

During the past decade, the spectrum of Raman scattered light from laser-produced plasmas has been observed under a wide variety of conditions. Such scattering has generally been attributed to the stimulated Raman scattering (SRS) instability. SRS is of interest to plasma physics as a relatively simple three-wave instability. It is of interest to laser fusion as a possible cause of reduced efficiency or lower gain in a laser-fusion target. From the standpoint of simple, linear theory, SRS is expected to occur at all densities from a lower limit, imposed by Landau damping of the electron plasma wave that is driven by SRS, to an upper limit of one-quarter of the critical density of the laser light (or of the maximum density in the plasma). In contrast, the observed SRS light is often quite structured in both spectrum and time. Both hydrodynamic effects and nonlinear, indirect interactions between SRS and other instabilities are possible explanations of such structure. In the present talk, I will present examples of such structure, emphasizing data from experiments using more than one kJ of laser energy to produce relatively long-scalelength, planar plasmas. I will focus as well on the presence or absence of a "gap" in the SRS spectrum at wavlengths just below twice the laser wavelength, and will comment on the implications of the data.

High Density Compression of Hollow Shell Target by GEKKO XII and Laser Fusion Research at ILE Osaka University

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High density compression more than 600 times solid density has been verified experimentally with diagnostics which were carefully examined and calibrated for the accuracy and applicability. The key technical issues to achieve a high density compression are the uniformity of the laser illumination and of a pellet. The kinetic effects in the energy transport by electrons are treated rigorously in the simulation to explain the experimental results.

The implosion of cryogenic hollow shell pellet and fundamental investigation on Cannon-ball target are also reported.

INTERACTION PHYSICS III

S. Eliezer, Session Chairman

Radiation Damage in Single and Polycrystal CsI

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University of Illinois at Urbana-Champaign

CsI is a potential infrared window for lasers and infrared detectors in space. Such windows may undergo severe radiation bombardment that may damage them. It is therfore necessary to study the influence of neutrons and gamma rays on CsI windows. Such a study is presently performed at the University of Illinois' pulsed, TRIGA reactor by irradiating samples of CsI with a total dose to the sample of 0.1 Mrad per pulse.

The damage was assessed by measuring the radioluminescence at the peak of the pulse in the infrared (0.7-4.5 microns) and in the visible range (0.2-0.9 microns).

It was found that, at room temperature, the radioluminescence from single crystal CsI would decrease by 30% in the infrared and by 25 % in the visible within nine pulses. For polycrystal CsI, the radioluminescence in the visible range decreases by 60% within six pulses, but no infrared emission was observed. Finally, a heating-cooling cycle was shown to repair the damage.

INVESTIGATIONS INTO X-RAY DAMAGE TO THE FIRST WALL OF THE INERTIAL CONFINEMENT FUSION LABORATORY MICROFUSION FACILITY*

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The Inertial Confinement Fusion (ICF) Laboratory Microfusion Facility (LMF)[1] would be built in the 1990's to develop high yield targets and to use them for a variety applications. The LMF, presently in a conceptual design and critical issues phase, would explode targets with yields up to 1000 MJ one or two times a day. Several driver technologies and target chamber concepts are under consideration, but certain critical issues can be identified that are common to all LMF concepts. One of these is vaporization of the inside surface of the target chamber wall. Sandia National Laboratory (SNL) is pursuing a Light Ion Beam driven version of the LMF which, for reasons related to beam propagation, has a first wall only 150 cm from the target[2]. For the maximum target yield, and assuming a HIBALL type target[3], such a wall would experience an x-ray fluence of roughly 800 J/cm^2 spread out over a few ns.

A combined theoretical, computational, and experimental effort is required to address the issues of x-ray vaporization and its consequences to the survival of the first wall. I will present a simple model that leads to scaling laws for the peak pressure and impulse per unit area in the wall against x-ray fluence, pulse width, and wavelength. The pressures can drive shocks into LMF first wall material. I will present results of simulations with computer codes to verify the simple scaling laws and to demonstrate shock propagation in the first wall. X-ray vaporization experiments on the SATURN electron accelerator at SNL have been designed with the help of this analysis to mimic the conditions in an LMF first wall. I will present results of such experiments on several types of aluminum and graphite that are candidate materials for the LMF target chamber wall.

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* The author performed this work while a visitor to SNL. This visit and work were supported by Sandia and Lawrence Livermore National Laboratories.

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2. B. Badger, et al. University of Wisconsin Fusion Technology Institute Report UWDFM-768 (August, 1988).
3. G. A. Moses, et al., University of Wisconsin Fusion Technology Institute Report UWFDM-396 (1980).

SATURABLE MAGNETICS FOR LASER AND PLASMA INTERACTIONS

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Abstract

Recently, there has been a growing interest in producing short rise time electric and magnetic pulses for a wide variety of advanced uses including compact particle accelerators, X-ray sources and ultra-fast non-optical diagnostics. One route to achieve this is through intense laser beams. Lasers can transport power densities which are several orders of magnitude better than electric transmission lines due to their spatial and temporal coherence. Indeed, 1000 T pulsed magnetic fields were produced in a coil connected to tiny capacitor charged by exposing one of its plates to an intense CO2 laser pulse.

An alternative way to sharpen electric and magnetic pulses is by inserting saturable magnetic switches between the capacitor bank and the load. When the magnetic field intensity, around a saturable magnet is increased, its permeability first rise and then "switched off" near the vacuum value. In certain applications, the switching time may take only a few hundred picoseconds, and thus may enhance electric and magnetic pulses produced in laser-plasma interactions

In this article we will demonstrate two applications of saturable magnetics related to laser-plasma experiments. First we will present numerical methods used to estimate the response of circuits with magnetic switches. Then, the response of a ferrite loaded single-turn coil connected to a laser-driven capacitor plates will be analyzed in details. Finally, we will present a design procedure of a magnetic switched pulser for a repetitive plasma focus device. Unique features of this pulser include the efficient conversion of high voltage utility supply into 50/60 Hz pulses and the partial recovery of the electrical energy.

ICF DRIVERS

H. Lowdermilk, Session Chairman

GLASS LASER DRIVERS FOR ICF

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Neodymium glass lasers have been the most productive drivers for ICF experiments in the past. This presentation will briefly review the prospects for constructing an affordable glass laser driver at an energy of about 5 MJ, which is adequate to achieve significant thermonuclear yield.

GLASS LASER TECHNOLOGY

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Advanced concepts in frequency conversion, phase conversion and pulse shaping of solid state lasers provide the means to achieve energy, irradiation uniformity and affordability requirements for ICF driver scaling.

This work was supported by the U. S. Department of Energy Division of Inertial Fusion under agreement No. DE-FC03-85DP40200 and the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics.

LIGHT ION BEAM DRIVERS FOR INERTIAL CONFINEMENT FUSION

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Intense beams of light ions are being developed on the PBFA II accelerator at Sandia for application to ICF. A program overview is presented together with a conceptual design of a driver for the LMF.

HEAVY ION ACCELERATORS AS DRIVERS FOR INERTIAL CONFINEMENT FUSION POWER PLANTS

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Because of their expected high efficiency, high repetition rate, long lifetime, and good reliability, heavy ion accelerators are an attractive driver option for inertial confinement fusion (ICF) power plants. The important issues for such accelerators have been beam quality (required for a small focus) and cost.

This paper will give a summary of our results on beam quality and accelerator cost as well as an overall assessment of the status and promise of heavy ion fusion.

*Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

KrF LASER DRIVER

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KrF lasers present a very attractive option for future ICF systems. The recent full system integration of Aurora has demonstrated the first step toward technical feasibility of this laser for fusion applications. Future systems will be based on extensions of the Aurora design concepts and will further evaluate the performance and cost potential of KrF.

INTERACTION PHYSICS IV

C. Joshi, Session Chairman

PARTICLE ACCELERATION WITH THE AXIAL ELECTRIC FIELD OF A TEM10 MODE LASER BEAM

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Due to their finite spot size, optical beams have small axial field components. For a Gaussian TEM_{10} mode, the axial electric field has a maximum on the optical axis while the transverse field vanishes there. The possible use of this axial field for the acceleration of highly relativistic particles has been studied.

The ratio of the axial to the maximum transverse electric field is inverse proportional to the spot size radius; for a spot size radius of $w_o \sim 400\lambda$, it is in the order of 10^{-3}. But the transverse field components seen by the highly relativistic particles are significantly reduced by the Lorentz transformation, thus the axial field components become important.

Finite spot size and axial field are inevitably connected to a phase velocity along the axis which is by approximately a factor of $(1 - \pi)(kw_o)^2)^{-1}$ above c. Consequently synchronism between wave and particle beam cannot be sustained for more than half a RF period. But due to the relativistic Doppler shift, particles can travel approximately the confocal length, kw^2, before the field reverses sign. The particle energy increase is proportional to the square root of the laser power, and lies in the order of 10 MeV for laser powers 10^{12}W.

Laser Interaction and Related Plasma Phenomena Workshop
November 6-10, 1989

Abstract

Demonstration of Frequency Upshifting of Electromagnetic Radiation by Rapid Plasma Creation

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UCLA / LBL / LLNL Collaboration

In this paper we demonstrate that when a plasma is created, quasi-uniformly and rapidly around a monochromatic electromagnetic wave, the frequency of the electromagnetic wave is upshifted. The power conversion efficiency of this process can be on the order unity. If the plasma density is continuously but rapidly varied in time, it is possible to obtain chirped radiation. Also, if the plasma density is larger that the critical density of the source wave, then a significant amount of power is converted to waves with frequency above the plasma frequency. We describe an experiment in which 30.7 GHz source radiation confined in a cavity resonator (TE_{01} mode) is upshifted by laser ionization of azulene vapor up to 77 GHz. The importance of coulomb and neutral collisions affects the power conversion efficiency at higher plasma densities. However, the power conversion efficiency is > 10% when the radiation is shifted by 1-5 GHz.

Abstract for International Conference LASER INTERACTION AND RELATED PLASMA PHENOMENA Monterey,Cf. 6-10 Nov. 1989

Laser-Plasma Double Layers: Generalization to Degenerate Electrons and Nuclei

S. Eliezer [a], H. Hora [b,c], R.S. Pease [b,d], A. Scharmann [c], and D. Schwabe [c]

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The study of the nonlinear force of laser-plasma interaction led to the discovery of dynamic internal electric fields in inhomogeneous plasmas and to double layers. The resulting surface tension in cavitons and at plasma boundaries (due to the faster emitted electrons) results in stabilization against the Rayleigh-Taylor instability. The same occurs with the degenerate electron gas within the ion lattice of a metal: the electrtons try to leave with the Fermi energy until a double layer is built up. The resulting surface tension immediately agrees with the measured values from metals. This can be applied to explain the driving surface force of the Marangoni flow by the electron flow in the surface layer. It further results in electron layers between metals and insulators or adsorbed molecular layers with consequences for the desorption process and metal catalysis. We further derive Hofstadter's charge decay in nuclei from Debye lengths and calculate immediately the measured surface energy of nuclei using the relativistic Fermi energy.

A REVIEW OF THE BACK-LIGHTED THYRATRON

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A new optically triggered switch that is useful for high power applications was discovered[1] and is being developed at USC. The optically triggered switch is a back lighted thyratron (BLT), a name that is indicative of its method of operation and the dense glow characteristic of its discharge. The BLT differs from laser triggered spark gaps in that the laser initiates a *glow* discharge, closing the switch using *unfocussed* UV incident on the back surface of the cathode. The BLT operates with a discharge that is a uniform, dense glow rather than a spatially inhomogenious arc. The uniform high density plasma and very high density cathode that have been demonstrated will be discussed, and applications to new forms of plasma based devices will be presented.

The glow mode operation, switch characteristics, and high plasma density have been found in research conducted at USC to be the result of a super-emissive thermionic cathode[2]. This cathode is also is responsible for operation of the pseudospark switch. The cathode is self-heated by ion bombardment during the closing phase of the discharge[3], allowing the switch to operate in a glow mode at very high current, and with very high current rate of rise. The cathode emits currents in excess of 10,000 A/cm^2 over cathode areas of $\approx 1\ cm^2$.

Only a small amount of optical energy is required to initiate the discharge with a delay of $\approx$ 100 nsec and jitter of $\approx$ 1 nsec. The BLT has been triggered using light from various UV lasers, using a flashlamp, with UV from a laser fed through an optical fiber, using light from a flashlamp that is also sent into the switch through an optical fiber, and using the light emitted from a high voltage spark in air. In a recent application, a three-stage Marx bank incorporating the BLT has been operated, demonstrating a glow device with fiber optic triggering is a candidate for applications formerly requiring spark gaps.

This talk will also discuss the application of the BLT and the high density plasma to the development of practical plasma based devices to be used to test and develop concepts for plasma based accelerators, electromagnetic sources, and related devices such as plasma lenses, and electron beam devices.

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[3] Hartmann, W., V. Dominic, G. Kirkman, and M.A. Gundersen, J. Appl. Phys. 65, 4388 (1989).

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ACCELERATION OF ELECTORNS TO TeV ENERGY BY LASERS IN VACUUM

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For the different acceleration schemes of electorns by lasers to very high energies, schemes without effects by surfaces, dielectrics, or plasmas are considered, only using vacuum intereaction between laser and electrons. One scheme follows the lateral nonlinear forces in laser beams, a second one the motion of electrons in accelerated intensity minima of laser fields, and a third one is based on the exact relativistic and Maxwellian equations of motion of electrons in plane propagating waves where no complete numbers of waves are acting. Conditions are elaborated under which electrons should achieve energies in the TeV range.

NUCLEAR-INDUCED UV FLUORESCENCE

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An experiment is in progress to develop nuclear pumping of UV fluorescent gases which can be used to power the optically-pumped atomic iodine laser. This laser utilizes compounds such as CF_3I or C_3F_7I, resulting in lasing at 1.3 micron. UV fluorescence can be produced by the interaction of energetic products from the $n(^{10}B,alpha)^7Li$, and $n(^3He,T)p$ reactions with a fluorescing gas. The goal of the present phase of the work is to select an optimal gas (or gas mixture), such that the fluorescence efficiency, coupled with the overlap between the fluorescer spectral output and the photodissociation cross-section of the lasant, will be maximized. The ^{10}B reaction is being used presently in the form of a thin coating on the test cell wall; ^3He will be used later as a fluorescer gas diluent. Neutrons are provided by the U. of Ill. TRIGA reactor. Fluorescing eximer mixtures suggested by previous workers for this application include XeBr (282 nm)[1] and KrF/Ar_2F (249, 284 nm)[2]. XeBr is currently being investigated, with results to date to be presented.

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Development of High Power KrF laser for ICF Laser Driver and Laser Interaction Experiments

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We briefly report high power KrF laser system and the research for laser plasma interaction in ILS.

The system has three staged amplifiers of 600J output energy. Angular multiplexed 5ns beamlets will be brought to the target with maximum averaged intensity up to $10^{15}W/cm^2$.

Target experiments have been started with one beam of our system. The laser plasma interaction of short wavelength laser will be investigated, which includes the absorption and radiation processes, the preheat effects and the filamentation problem. The target experiments were carried out using ns and ps laser for varying scale length of plasma. The irradiance was $10^{13-14}W/cm^2$ for 20ns pulses and $10^{14-15}W/cm^2$ for 2ps pulses. In the ps laser system, undesirable prepulse was controlled by a saturable absorber (power ratio;10^{-7}). Good absorption properties were observed even for the long scale length plasma. The ps pulse interaction suggested that the absorption was large sensitive to the prepulse for small scale length plasma.

A Proposed Microwave Plasma Mirror

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Abstract

Studies of the reflectivity of a stack of plasma layers under various conditions are presented. The mirror concept is based on a high density plasma source (~ 10^{15} cm^{-3}) that works in the superdense glow discharge mode. The effects of the plasma density, layer thickness and temperature on the total reflectivity and diffused boundaries will be discussed. High reflectivity plasma mirrors are of interest for free electron laser technology because they will withstand high power radiation and also allow for injection of the electron beam into the optical cavity.

In an underdense plasma-vacuum interface the reflected fraction of a weak incident electromagnetic wave is usually less than 1%. However, if the plasma source generates successive equally spaced plasma layers, the reflected waves add constructively, and reflectivities on the order of 90% or higher can be obtained with a small number of layers. For example, for electromagnetic radiation of 1 mm wavelength, reflectivities of 88% can be obtained from a stack of 11 layers of plasma of density 0.6 nc, layer thickness $\lambda/4$, and temperature of 1 eV. Each layer is assumed to be separated from each other by odd multiples of vacuum regions of the same thickness. The reflectivity is then limited by collisional absorption, which is ≈10% of the incident radiation. If the plasma temperature is 10 eV, the total absorption is reduced to 1%, and the fraction of reflected radiation increases to 97%.

Work sponsored by the Army Office Research.

PANEL "VIEWS ON FUTURE DIRECTIONS IN ICF"

Moderator: D. Cartwright (LANL)
Panelists: E. Storm (LLNL)
J. Knauer (LLE, U. Rochester)
B. Ripin (NRL)
S. Nakai (ILE, Osaka U.)
P. Mulser (T. H. Darmstadt)

TARGET PHYSICS I

K. Niu, Session Chairman

Precision Direct-Drive Experiments on OMEGA*

R. L. McCrory, J. M. Soures, C. P. Verdon, F. J. Marshall, S. A. Letzring, S. Skupsky, R. L. Kremens, J. P. Knauer, H. Kim, R. Short, T. Kessler, R. S. Craxton, J. Delettrez, R. L. Keck, and D. K. Bradley

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Inertial confinement fusion (ICF) requires high compression of fusion fuel, to densities approaching 1000 times liquid density of deuterium-tritium (DT), at central temperatures in excess of 5 keV. A critical test of direct-drive laser-fusion has demonstrated DT compressions in the range of 100 to 200 times liquid density in experiments on the University of Rochester's OMEGA laser facility. The high-density cryogenic experiments used 351 nm laser pulses with energies of 1500 to 1800 J and pulse widths in the range of 600 to 700 ps. A modification of Kato's technique[1] to alter the phase fronts of the laser beams to produce effectively over 250,000 overlapping beamlets on target was implemented by using two-level distributed phase plates (DPPs).[2]

Although the experiments achieved high compressed DT fuel densities, there were significant deviations in neutron yield between the experiments and that expected on the basis of one-dimensional code calculations of the expected target performance. The deviations are believed to result from nonuniform implosion of fuel and shell material due to irradiation nonuniformities not removed by the DPPs as well as due to mix generated by hydrodynamic instabilities of the Rayleigh-Taylor type. To address these issues, we have developed a new technique for smoothing laser irradiation on target, smoothing by spectral dispersion (SSD).[3] To eliminate the interference structure which results from breaking up a laser beam into a large number of beamlets, techniques such as induced spatial incoherence (ISI)[4] developed by researchers at the Naval Research Laboratory have been proposed. ISI relies on the use of a broad bandwidth laser which is basically incompatible with the narrow spectral bandwidth required to achieve high-efficiency tripling in a high peak-power solid-state glass laser system. SSD also requires the use of a broad bandwidth, but the spectrum is dispersed spatially in such a manner to allow high-efficiency frequency tripling. Smoothing of the interference pattern is achieved from the interference of the beamlets of different frequency. Improvements in irradiation uniformity through the use of SSD, may lead to reduced hydrodynamic instability growth and nearly one-dimensional capsule performance. Recent implosion results using SSD on OMEGA will be presented.

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* Supported by the U. S. Department of Energy under agreement DE-FC08-85DP40200 and by the Laser Fusion Feasibility Project at the University of Rochester.

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HIGH-GAIN DIRECT-DRIVE CAPSULE FOR ICF

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In this work numerical calculations obtained with high-gain targets driven by laser, light ion and heavy ion beams are shown. A 1 mg DT capsule driven by 0.35 μm laser light, 3σ MeV Li^+ beams have been assumed.

The composition of the targets is a low-z material layer, to absorb and convert the beams into hydro-motion, and a layer of 1 mg of criogenic DT. The initial aspect ratio of the targets is moderately high to obtain a good hydrodynamic efficiency.

The major conclusion of this work is the similar energies needed to have ignition conditions in so different targets under different illumination conditions. High gains could be obtained with energies of a few MJ.

ELECTRON MOTION IN PLASMA IRRADIATED BY STRONG LASER LIGHT

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Recently, the pulse width of the laser light can be shorten to 10^{-15}s, hence the strong intensity of 4.42×10^{23}J/m^{2}s (whose electric field is 1.29×10^{13}V/m) accelerates the electron to the light speed during a pulse width. The electron accepts a strong acceleration irradiated by such an intense laser light, and radiates an retarded electromagnetic wave. The reaction force due to the self-radiated electromagnetic wave acts on the electron motion. By taking the reaction force into consideration, the equation of motion for the electron includes a third order differential term regarding time. The damping factor of electron motion caused by this reaction force depends on the laser frequency. In the range of γ-rays (ω>7.5×10^{22} rad/s), the damping factor becomes significant. Although the electron with the light speed experiences the damping in the oscillation with slower frequency, the damping disappears when the electron velocity reduces to 0.98 times the light speed.

Next, the forces are investigated on electrons caused by the collective motion of electron beam. In our case, the laser light is considered to accelerate the local electron cylinder. Accompanied with this group motion of electrons, the electric field as well as the magnetic field is induced. The intensity of induced magnetic field is not so high in our case, but the electric field induced by the acceleration of the electron beam becomes rather high and cancels the electric field of laser light. At $\omega t=\pi/2$, the beam obtains only the velocity of 1.89×10^4m/s, although it should obtain the light speed without the induced electric field. The second electric field comes from the finite length of the electron beam. Near the reading edge the electrons are decelerated, while near the trailing edge, the electrons are accelerated. Thus the beam is bunched during the motion, but the effect is negligible in comparsion with that by the first electric field.

TARGET PHYSICS II

D. Hewett, Session Chairman

ADIABATIC COMPRESSION OF FUEL IN ICF TARGET

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Since fusion reaction rate in DT fuel is proportional to the square of fuel density, the high fuel density in an ICF reactor promises to afford us a source with a high energy density. The Tokamak plasma of $1000m^3$ corresponds to the ICF fuel of $1mm^3$. This fact suggests that an economical fusion reactor has a possibility to be constructed in the case of ICF.

Thus the essential point to achieve ICF is to compress the fuel to 1000 times the solid density in an adiabatic way. The adiabatic compression by using the similar solutions[1,2] requires a higher pusher pressure than the fuel pressure during the implosion, and cannot be applied to the practical target, because the required final fuel pressure is so high as 10^{18}Pa. The practical adiabatic compression of the fuel will be performed in the process of supersonic flow in a converging nozzle[3] (in a spherical target). The fuel obtains a supersonic velocity accelerated by a relatively low pusher pressure (of order of 10^{13}Pa). The decreasing crossectional area for the supersonic fuel flow changes the fuel momentum to the fuel pressure adiabatically.

The adiabatic compression of the fuel in the supersonic flow in a spherical target will be done with the uniform implosion motion. For the uniform implosion motion, the rate of the dispersion to the average value of pusher pressure should be less than 2%. To attain such a uniform pusher pressure on the boundary between the pusher and the fuel, pusher pressure smoothing by radiative energy transfer through the radiation gap between the pusher layer and the fuel layer is necessarily functioned in a target. To realize the radiative energy flux density of $5x10^{13}W/cm^2$ through the radiation gap, the beam energy of 12MJ should be launched on a target during 30ns.

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RADIATION AND ATOMIC PHYSICS MODELS FOR ICF CAPSULES

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A one-dimensional radiation hydrodynamic code, called SARA that implicitly solves the multigroup radiation transport equations has been developed. A high-order differencing algorithm as well as multifrequency gray synthetic acceleration techniques are used to obtain a robust algorithm that can be used for radiation energy transport problems. Opacity data comes from, well the DENIM atomic data library, or well from analytical expressions. With these performances the code has been widely used to analyze ICF capsules.

To investigate radiative regimes and also indirect-drive capsules, the code is being coupled with a non-LTE average-ion collisional-radiative model, called PLEYADE, which solves time dependent rate equations, providing the electron populations of each atomic shell.

The presented results demonstrate the need of the radiation and atomic physics coupling to analyze ICF capsules.

IMPLOSION CHARACTERISTICS OF RADIATION–DRIVEN FOR HIGH GAIN LASER FUSION

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Abstract

This paper theoretically discusses the implosion characteristics of radiation–driven high gain laser fusion. For this purpose, the authors estimate some important characteristic quantities, including efficiencies, fuel compression and hot spot ignition etc., in addition, the paper emphasizes some major harmful factors which have to be controlled for successful performance.

TARGET PHYSICS III

B. Ripin, Session Chairman

X–RAY CONVERSION IN HIGH GAIN RADIATION DRIVE ICF

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Abstract

In this paper, the conversion mechanizm of soft X–ray emission, efficiency and the related physics for high gain ICF are analysed; the radiation temperature in hohlraum is estimated.Finally, the numerical results of laser cavity —target coupling for typical models are given and discussed.

MEASUREMENTS OF HYDRODYNAMIC INSTABILITIES AND TURBULENCE PRODUCED BY LASER-ACCELERATED TARGETS

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Thin foils which are accelerated to high velocities by a laser experience the Rayleigh-Taylor (RT) instability. Such foils can also induce instabilities in other objects. For example, the laser-accelerated foil can be made to collide with a second foil placed behind it, launch a shock in the second foil, and push on it. In this way, the Richtmyer-Meshkov (RM) instability or the RT instability may be induced at the interface between the two materials. Foils which are accelerated into a background atmosphere induce turbulence in that atmosphere. All of these instabilities are important in many man-made and natural situations that occur, for instance, in inertial confinement fusion, supernova, or the earth's atmosphere.

This presentation describes experiments at N.R.L. which have studied the above phenomena. The single-foil RT, and inter-material RT/RM instability growth rates were measured by simultaneous x-ray backlighting of the foils (to measure instability-caused material transfer) and x-ray sidelighting the foils (to measure their motion). Thus, the instability growth rate, the wave number k, and the acceleration g are simultaneously measured on each shot. In the case of the RT instability, this permits accurate and reliable comparison to the classical growth rate $(kg)^{1/2}$ and to hydrodynamic calculations which include phenomenology absent from the classical theory. The experiments explored a wide range of parameters such as instability wavelength (25,33,50,75,85,and

100 um), foil thickness, amplitude of initial foil perturbation (0.1 to 1um), and foil material.

An additional feature of our experiments was the use of an ISI-laser-smoothing method to produce very smooth irradiance profiles on the foil surface. Such laser profiles accelerate foils very uniformly when measurable instabilities are not present. We have accelerated foils to speeds of 0.5-1 x 10^7 cm/sec with peak-to-peak nonuniformity of less than +/-1.5%.

Turbulent fluctuations in a background gas were created by accelerating smooth or perturbed foils, in an atmosphere of 0 to 10 torr of hydrogen, helium, nitrogen or xenon. In other experiments plasma jets were used to induce the turbulence. The turbulent fluctuations in the index of refraction (or, with some assumptions, the electron density) are spatially and temporally resolved with phase-contrast microscopy, dark-field shadowgraphy, and holographic interferometry. Visible light emission from the turbulent region is photographed with a gated imager. From these measurements the power spectral density (PSD) and other characteristics of the turbulence are determined.

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Ninth Workshop of Laser Interaction with Matter
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Early-time "Shine-through" in Laser Irradiated Targets

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Abstract

The intense laser light used in laser fusion normally interacts with the plasma formed at the surface of the target. Before the establishment of this plasma, the laser light is incident on the solid surface and may propagate into the target. It has been suggested that this early time "shine-through" and the resultant energy deposition may create non-uniformities and act as a seed for instabilities, resulting in a breakup of the target shell. We present results of experiments in which both glass and polymer targets were irradiated with 600 ps. pulses of 351-nm laser light focused to intensities of 10^{12}-10^{14} W/cm^2 by an f/3 lens. A similar lens at the rear side of the target was used to image the transmitted light onto the slit of a streak camera (time resolution) and onto film (spatial resolution). Our streak camera results show that both glass and plastic targets transmit the early portion of the laser pulse before becoming opaque. We have measured this cut off point for a range of materials and coatings and have also made estimates of the total integrated energy which is transmitted during the initial stage of the laser pulse. In addition, we use a 10 ps. optical probe beam to study surface plasma generation and dielectric breakdown.

To mitigate the effect of "shine-through" we have coated planar and spherical targets (made of either glass or polymers) with various layers. We present the results of this study and show the effect of various overcoatings which reduce the shine-through to acceptable levels.

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Self-focusing in transparent dielectric media and subsequent surface break-down and plasma production.

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When transparent dielectric media are irradiated with high intensity laser pulses ($I_L \geq 10^{12}$ W/cm^2), a number of processes occur in rapid succession. At very low intensities ($\ll 10^8$ W/cm^2), the laser light is typically transmitted without significant attenuation or nonlinear interaction. At higher intensities ($>10^9$ W/cm^2), self-focusing and/or filamentation occurs inside the medium, which is then followed, at still higher intensities ($>10^{10}$ W/cm^2), by surface plasma formation leading to complete absorption or reflection of the incident laser light. This sequence of processes has been observed at pulse durations from 10 psec to several nsec. In this study we use a 10 to 20 psec optical probe beam to identify the various processes and assess their potential importance to direct drive laser fusion experiments. Of particular interest are multi-layer targets which are typical for laser fusion experiments. The interfaces of such layered targets are particularly prone to low intensity laser damage, and as such may act as seeds for hydrodynamic instabilities in laser-accelerated targets.

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Laser Induced Breakdown and High Voltage Induced Breakdown on Metal Surfaces

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Breakdown and plasma formation on surfaces is a fundamental process in laser target interaction experiments as well as in other areas of pulsed power technology. The initial plasma formation on the surface of a laser irradiated metal target is very non-uniform. Micron-sized plasma spots form within nanoseconds. Quite similar, the initial plasma formation on the surface of a cathode of a vacuum arc, vacuum diode, and many other discharges is highly non-uniform. Micron-sized cathode spots form within nanoseconds.

The concept of explosive electron emission from a cathode spot is well established in the literature. However, opinions differ concerning the detailed processes which lead to the explosive formation of a dense cathode spot plasma and its structure. The current density j and the electric field E influence field emission of electrons, joule heating, and plasma formation. Estimates of j for a cathode spot vary by orders of magnitude between 10^5 A/cm^2, reference 2, and 10^9 A/cm^2, reference 3. This indicates that the details of the explosive electron emission process are not yet well understood.

Unipolar arcing[4] represents a discharge form which easily leads to explosive plasma formation. Power dissipation for an unipolar arc is considerably higher than for field emitted or space charge limited current flow. Using a laser produced plasma it has been demonstrated that unipolar arcs ignite and burn on a nanosecond time scale without any external electric field being applied, E=0. Similar unipolar arc craters have now been observed on the cathode surface of a pulsed (20 ns) vacuum diode with an externally applied field of E=1MV/2.5 cm. The experimental results show that cathodes spots are formed by unipolar arcing. The localized build-up of plasma above an electron emitting spot naturally leads to an electric field distribution which drives the unipolar arc. The high current density of an unipolar arc provides explosive plasma formation.

Unipolar arcing represents a basic form of a small scale discharge which contributes to phenomena like laser induced breakdown and formation of cathode spots in a unique way.

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INTERACTION PHYSICS V

C. Deutsch, Session Chairman

LABORATORY SPACE PLASMA PHYSICS*

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ABSTRACT

Space plasmas span a broad range of physical parameters and extend over large dimensions. They frequently involve several non-equilibrium components which interact with each other and the ambient magnetic field to drive a rich collection of plasma instabilities and phenomena, many of which were first uncovered in space. Great progress has been made in discovering and understanding many of these processes through rocket and satellite experimentation and plasma theory advances. However, actual space experiments are very expensive and infrequent. Moreover, they offer limited capability to perform the kind of interactive experiments required to understand the basic science involved. Laboratory experiments, on the other hand, can accommodate detailed studies which bring deep physical understanding and are relatively inexpensive. But, they often have physical parameters far from those in space and run the risk of being irrelevant to space phenomena. The most efficient approach, therefore, is an integrated effort involving space experiments, laboratory experiments, and theory. Laboratory experiments then help interpret space observations, verify theory, and can provide direction for future space experiments.

Laser-produced plasmas are particularly well suited for laboratory space plasma investigations. They can be formed with parameters either very close, or scalable, to many space and astrophysical plasmas and active space experiments.[1] We describe several such space-plasma experimental investigations using the NRL Pharos Laser Facility. One subject is the large Larmor radius (LLR) instability. Unexpected plasma structuring was first observed in the 1985 AMPTE magnetospheric barium release experiment,[2] then a theoretical explanation was offered proposing a new instability (LLR),[3] and finally, the instability was observed and extensively studied in the NRL laser experiment.[4] The insight obtained from the experiment, in turn, is guiding further theoretical development and future space-release experiments, such as the upcoming CRRES series. Another example, is the lower-hybrid velocity-shear instability, which is one of a new class of non-local instabilities which may occur frequently in space and laboratory plasmas.[5] The first observations of this instability were made recently in the laser experiment.[6] Several other space-related laboratory investigations will also be described, including: plasma jetting, super nova shocks, and turbulence generation from high Mach-number flows.

* Collaborators in this work are: P. Bernhardt, J. Crawford, G. Ganguli, J. Grun, J. Huba, A. Hassam, C. Manka, E. McLean, A. Mostovych, T. Peyser, J. Stamper.
Work is sponsored by the ONR and DNA.

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SHOCK WAVE DECAY AND SPALLATION IN LASER-MATTER INTERACTION

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Spall at ultra high strain rate ($10^7 sec^{-1}$) was investigated in a variety of materials using short pulsed laser induced shock waves. The intensities of our 3.5 nsec Nd: Glass laser were in the range 10^{10}–10^{12} W/cm^2, and the foil thicknesses in the 0.01-0.1 cm range. The laser generated shock wave pressure was in the domain of a few hundred kilobars. The controlled stepwise increase in laser energies allowed us to find the stages of damage evolution from incipient to complete perforation of the target foils.

A new experimental method was developed in order to calculate the decay of the laser generated shock waves. This technique enabled us to evaluate the laser induced spall pressure in different materials. In particular, experiments were performed on aluminum, copper and unidirectional carbon fiber epoxy composites. For the composites, the tensor character of the spall strength was demonstrated.

INTERACTION PHYSICS VI

T. Q. Chang, Session Chairman

3-d Particle Simulation of Ultrashort High Intensity Laser Interaction with Solid Density Hydrogen Plasma

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The interaction of ultrashort energetic laser pulses with solids is of great interest both as a source of x-ray pulses and as a new and interesting regime of plasma and solid state physics. If a pulse duration of a laser-light is so short that no significant hydrodynamic expansion of a matter takes place, the electric field of a laser interacts directly with a solid density matter. The quivering distance of electrons oscillating at a laser frequency exceeds easily the mean ion distance at a solid density. The oscillating electrons thus interact with many ions within a one oscillation period. In addition to that the ratio of the Coulomb energy to the kinetic energy becomes of the order of unity for such a high density plasma. The ions with which the oscillation electrons interact are also strongly correlated with each other in a strongly coupled plasma.

To simulate such a hot dense plasma, we have developed a 3-d two component particle code "SCOPE" in which both short-range and long-range forces are calculated. The short-range forces are computed by using a direct-particle summation over the spatially localized forces, and the effective potential between particles is the same as that introduced by Deutsch.[1)] The lon-range forces are calculated using particle-in-cell method.

We consider the case of the normal incidence of a laser light with a wavelength of 0.35 micronmeter on a solid density plasma. In this simple case the laser absorption efficiency can be calculated from the knowledge of the electrical conductivity of the plasma. An oscillating external electric field is applied to the system, consisting of 500 protons and 500 electrons. Observing the induced electric current density, we estimate the complex conductivity.

It is found that the real part of high frequency conductivity shows two distinct regions as a function of the applied electric field amplitude. For the small amplitude, namely, the quivering velocity is much smaller than the electron thermal velocity, the electric conductivity is determined by the electron-ion collision frequency. However for the large amplitude, the quivering velocity cannot be ignored compared with the thermal speed. The real part of the conductivity then starts to decrease with the increase of the amplitude. The observed conductivity, however, does not agree quantatively with the theory for the ideal plasma.[2)] The conductivity decreases very slowly with the increase of the amplitude. We believe that this is due to the fact that the oscillating electrons within a one period interact with the many ions which also correlated with each other.

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TWO-DIMENSIONAL CALCULATION OF SEQUENTIAL ELECTRON LAYER FORMATION BY CROSSED MICROWAVE BEAMS IN AIR AT LOW PRESSURE*

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Laboratory chamber experiments in low pressure (0.1-10 Torr) air with long pulse (150-600 nsec), 2.856 GHz crossed microwave beams, created by reflection of a single beam from a metal plate inclined at 45°, have shown that multiple, luminous electron density layers form in time toward the source of the incident beam.[1]

Previous two-dimensional calculations of microwave air breakdown in a rectangular waveguide with a computer code, which resolves each rf cycle of the driving electric field, required Cray computation times of roughly 0.5 hr/nsec.[2] Since simulation of long pulse experiments with a full cycle resolution code would take 75-300 hours per run, a code which follows only the pulse envelope has been developed. Initially the temporal and spatial electron density evolution in the x-y space transverse to the driving E_z field is described by a convective continuity equation with avalanche ionization as an electron source. The ionization rate is a function of air pressure and driving field amplitude and frequency. The electron convection is described by electric field drift and diffusion terms in the x and y directions. The electric field drift of electrons is caused by electrostatic fields calculated from spatial gradient free approximations to the Maxwell magnetic curl equations. The current densities in these equations are comprised of diffusion and drift terms. The drift terms are characterized by a complex, steady state, sinusoidal conductivity, which uses the sum of the ionization rate and the electron-neutral momentum transfer rate for the collision frequency.

After the peak electron density has grown to a few percent of the critical density, the three initial electrostatic equations are replaced by another set. One of these is a nonconvective continuity equation, in which drift and diffusion are ignored, but ionization is retained. In addition, a harmonic, slowly varying envelope approximation to the driving field wave equation produces two coupled diffusion equations for the real and imaginary parts of the driving field envelope. These two sets of equations are numerically approximated by finite differences and solved on a Cray XMP computer.

Calculations are done at 1 Torr with a linearly ramped pulse, which reaches a plateau value of 0.159 MV/m at 80 nsec. At about 53 nsec after the simulation starts, the peak electron density in a small blob at 3.2 cm from the metal plate reaches 1.5% of the critical density. This blob slowly grows into a long (~22 cm) layer parallel to the plate. This layer reflects the incident beam, forming a standing wave pattern in the source direction. A second layer appears at 94 nsec. Three additional layers appear by 113 nsec. Calculated layer formation times vary from 57 nsec for the first layer to 107 nsec for the fifth layer. Experimental layer formation times from streak photography vary from 75 nsec for the first layer to 85 nsec for the fifth layer. Calculated electron density distributions will be compared with experimental luminosity patterns.

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Fission-Induced Inertial Confinement Fusion for Power Generation and Cold Fusion with Electrolysis

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ABSTRACT

A theory of neutron-induced tritium-deuterium fusion is developed, based entirely on previously measured cross-sections of known nuclear reactions. The process involves self-sustaining chain reactions: (1) $n + {}^6Li \rightarrow {}^4He + T$ and/or $n + {}^7Li \rightarrow {}^4He + T + n$, and (2) $T + D \rightarrow {}^4He + n$, in $Li - D$ plasma or pellet surrounded by Li and other blankets and by neutron reflectors. It has been suggested [1] that the excess heat generation observed by Fleischmann, Pons, and Hawkins (FPH) in their electrolysis experiment[2] may be due to this fission-fusion process at room temperature. The proposed fission-fusion process will be first described in a more general context without the use of electrolysis for the purpose of suggesting new designs for large-scale fission-fusion reactors for power generation.[3] Then, the FPH effect [2] will be described as a special case of the proposed fission-fusion process which involves electrolysis with a Pd cathode. Recent experimental tests and evidence for the chain reaction hypothesis will be discussed.

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TWO-TEMPERATURE EOS EFFECTS IN LASER MATTER INTERACTION

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We developed a two temperature EOS for a plasma medium. The col electron temperature is taken from SESAME tables, while the therma contribution of the electrons are calculated from the Thomas-Fermi Dirac (TFD) model. The ion equation-of-state (EOS) is obtained by usin the Gruneisen-Debye solid-gas interpolation method. These EOS are wel behaved and are smoothed over the whole temperature and densit regions, so that also the thermodynamic derivatives are well behaved. Moreover, EOS were used to calculate the average ionization $\langle Z \rangle$ an $\langle Z^2 \rangle$ of the plasma medium. Furthermore, the thermal conductivitie have been calculated using an extrapolation between the conductivitie in the solid and plasma (Spitzer) states. The two temperature EOS, th $\langle Z \rangle$ and $\langle Z^2 \rangle$ and the thermal conductivities for electrons and ion were introduced into a two fluid hydrodynamics code to calculate th laser plasma interaction in aluminum and gold slab targets. It wa found that the two EOS is important mainly from the ablation surface outwards (toward the laser). In particular the creation of cavitons in the distribution of electrons is here predicted, spetially for light materials as aluminum.

CHARGED PARTICLE INTERACTIONS I

C. Choi, Session Chairman

ION BEAM-DENSE PLASMA INTERACTION OF ICF INTEREST

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Heavy ions-dense plasmas interactions of ICF interest are timely reviewed. Emphasis is laid on basic processes determining the enhanced stopping power as well as the projectile steady charge state in plasmas, which are contrasted to the corresponding cold gases ones. Scaling laws show that within a Born-RPA approximation, the most excited target electrons exhibit the largest stopping capabilities. Then, standard plasma discharges provided fully ionized, and conveniently displayed on existing acceleration beam lines, could behave as efficient benchmarks for testing the basic features of the ion-plasma interaction. The various experimental programs are presented altogether with the last theoretical developments. A certain attention is given to the stopping by bound but highly excited electron target orbitals, which are likely to account for strong coupling effects within the ion fluid component.

+Associé au C.N.R.S.

Tight Focusing of Proton Beam and Its Interaction with Targets

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A high-bright, self-magnetically insulated, coaxial ion beam diode, "Plasma Focus Diode" (PFD), was successfully developed and studied systematically. Using such the tightly focused beam, we investigated the ion beam energy deposition in the intense beam-target interaction.

Experimental performance involve diode operation, ion current density measurement, beam divergence measurement, ion beam energy spectrum measurement and measurement of ion energy loss in targets. The PFD consists of a pair of coaxial cylindrical electrodes with diameters of 35 mm (anode) and 22 mm (cathode), respectively. The axial length is 40 mm. The cathode is perforated with holes (1 mm in diameter) with a transparency of ~ 40 %. The ions focus two-dimensionally toward the central axis. By using the pulse power machine "ETIGO-Ⅱ", we operated the diode at voltage of 1.5 MV and total current of 150 kA. At different positions along the axis of PFD, the focusing radius was measured to be 0.18 ~ 0.25 mm by Rutherford-scattering pinhole camera, while the ion current density on anode surface was measured to be 1.4 ~ 1.9 kA/cm^2 by bias ion collector. The ion beam power density at the focus was estimated as ~ 0.1 TW/cm^2. The ion beam energy spectrum was measured by a time-resolvable Thomson-parabola spectrometer (TPS) after scattered by a gold foil (0.22 μm), and the measured ion energy spectrum is identified with the inductively corrected diode voltage. In beam-target interaction experiments, the following targets were used: 1-μm gold, 3-μm and 5-μm copper and 3-μm and 7-μm aluminium, where the ion energy spectrum was measured by TPS. In comparison with the energy loss for cold target (calculated by Bethe equation), enhanced energy

deposition was observed for aluminium targets of both 3 μm and 7 μm thick with maximum enhancement ratio of ~ 2.

Theoretical efforts involve diode-behaviour analysis and simulations of beam-target interaction. We analyzed diode impedance behaviour through calculations of field distribution, electron trajectories and diode plasma development. In the simulation of beam-target interaction, we applied bound electron and free electron stopping power, thermal equilibrium model, radiation and conduction model and hydrodynamic expansion model. The simulation results of proton energy loss in 7-μm aluminium are in good agreement with experimental data.

Following above experimental and theoretical studies, physical understanding was obtained on the PFD and the associated interaction with target.

THEORETICAL ANALYSIS OF CHARGE NEUTRALIZATION OF THE INTENSE LIGHT ION BEAM

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Abstract

In order to extract a practical amount of energy from a target, high dense beam will be required to be launched to the target in the case of light ion beam ICF[1]. The effects of electrostatic fields induced at the two edges (lead and trailing edges) are dominant in such a dense light ion beam, during the propagation[2]. This intense electric filed comes from the nonneutralized light-ion-beam-charge at the two edges, and it causes the divergence of the propagating beam at initial step of the beam propagation especially in the intense light ion beam. Thus, the propagation of the intense light ion beam will be in difficulty even in the background plasma as well as in vacuum. The effect of the charge nonneutrality is reliefed as dense the background plasma is, because the back electrons gather to delete the beam charge within the time of the order of reciprocal of the electron plasma frequency of the background plasma. Hence, the complete elimination of the beam charge at the edge parts is impossible and if there is no special finesse, the beam would diverge and can not propagate to the target. To charge-neutralize at the edge parts is a necessary requirement to achieve the stable beam propagation, especially in the practically intense light ion beam[3,4]. One of the methods proposed here is to make the beam pass through the high density (electron rich) plasma region or thin plasma sheath in order to neutralize the beam-charge. In this case, the induced electric field at the leading edge motivates the electrons to follow up the ion beam and cancel out the electric filed, or some electrons would be captured by the electrostatic potential at the leading edge. This paper shows the mechanism how the beam ions capture electrons in the plasma, and makes the conditions clear for the stable propagation of the ion beam in the plasma.

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CHARGED PARTICLE INTERACTIONS II

W. Jiang, Session Chairman

Corona Plasma Instabilities in Heavy Ion Fusion Targets

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Abstract

The possibility that a beam of heavy ions could be the best driver for ICF is being pursued with renewed enthusiasm at LLNL. Among the reasons for continued interest are the efficiency and reliability of the accelerator and the relatively uncomplicated interaction of the beam with the ICF target. We have recently reexamined this beam-target interaction to insure that nothing has been overlooked and to establish better quantitative limits for target chamber scaling. Several plasma instabilities driven by a heavy-ion beam impinging on an ICF target have been considered. Potential instabilities include longitudinal electrostatic (two-stream) instabilities and transverse electromagnetic (filamentation or Weibel) instabilities. Since the ion beam may be accompanied by electrons, both electron-beam and ion-beam instabilities were considered. The electrostatic beaming instabilities saturate by formation of an electron tail. Though this tail contains an insignificant amount of energy, it can serve as the free energy source for anisotropy-driven modes. We have shown that this Weibel instability driven by this electron energy anisotropy is benign, strengthening earlier studies that have shown the slower ion Weibel instability to be unimportant. Finally, the beam ion-target electron instability was found to be suppressed by the gradient in the target density. Moreover, even if it were to grow, it would saturate at a benign level.

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An Implicit Fluid-Particle Model for Ion Beam-Plasma Interactions*

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A new method for modeling the hydrodynamic response of matter irradiated by ion beams is presented and illustrated with applications to the fluid flow of beam-driven ICF target plasmas. The numerical model uses a full particle-in-cell (PIC) representation, in which the plasma is completely described with finite-sized "particles" having mass, momentum, and energy. The method integrates the equations of motion for each particle implicitly in time, allowing the particles to move around on an arbitrarily-adaptive computational grid. The dynamic evolution of plasma fluid flow, using realistic equations of state, is then studied during and subsequent to interactions with impinging ion beams. The ion beam-plasma interaction physics are modeled with a 3-D ray tracing algorithm in which rays representing the beam stream through the computational grid of plasma particles. The PIC method developed here has minimal dissipation, no numerical diffusion, and is ideally suited for modeling distorted fluid flow such as that arising in ICF target implosion stability and symmetry studies. A conventional shock tube problem as well as 1-D and 2-D planar ion-driven ICF target implosions illustrate the properties of the present method.

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ACTIVE BEAM-CONTROL AND ACTIVE LASER-DIAGNOSTIC OF INTENSE PULSED ION SOURCES*

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To utilize the full potential of intense pulsed ion beams for inertial confinement fusion, it is necessary to transport and bunch the ion beams before the target irradiation. To do so, it is also inevitable to make an active control of the beam production and to investigate the fundamental particle behaviors in the diode gaps with an active laser diagnostics beforehand. So that, the both subjects as are shown in the title are described in this paper.

In our recent presentation [1], we proposed a new method to pre-trigger and to make initial anode plasmas of pulsed ion sources. With an additional pre-discharge along the anode surface before the arrival of the diode main pulse at the anode, we could change the turn-on delay and improve the diode and beam characteristics. After this presentation, we continued the same kinds of experiments to gather the detailed results, while a revised version of pre-discharge method with another external energy source was tried also to improve the impedance characteristics of the diodes.

In our recent another presentation [2], we showed our preliminary results concerning the second subject, an active laser diagnostics of the diode gaps. The time and spatial distributions of the neutral particles and electrons were observed with a resonant laser interferometry or a resonant laser scattering. After this presentation, we continued the same kinds of experiments with higher voltage of the diodes after the revision of the pulsed power and the diode sections.

For both items, we will show our recent results in more detail in the workshop.

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AFFILIATIONS

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